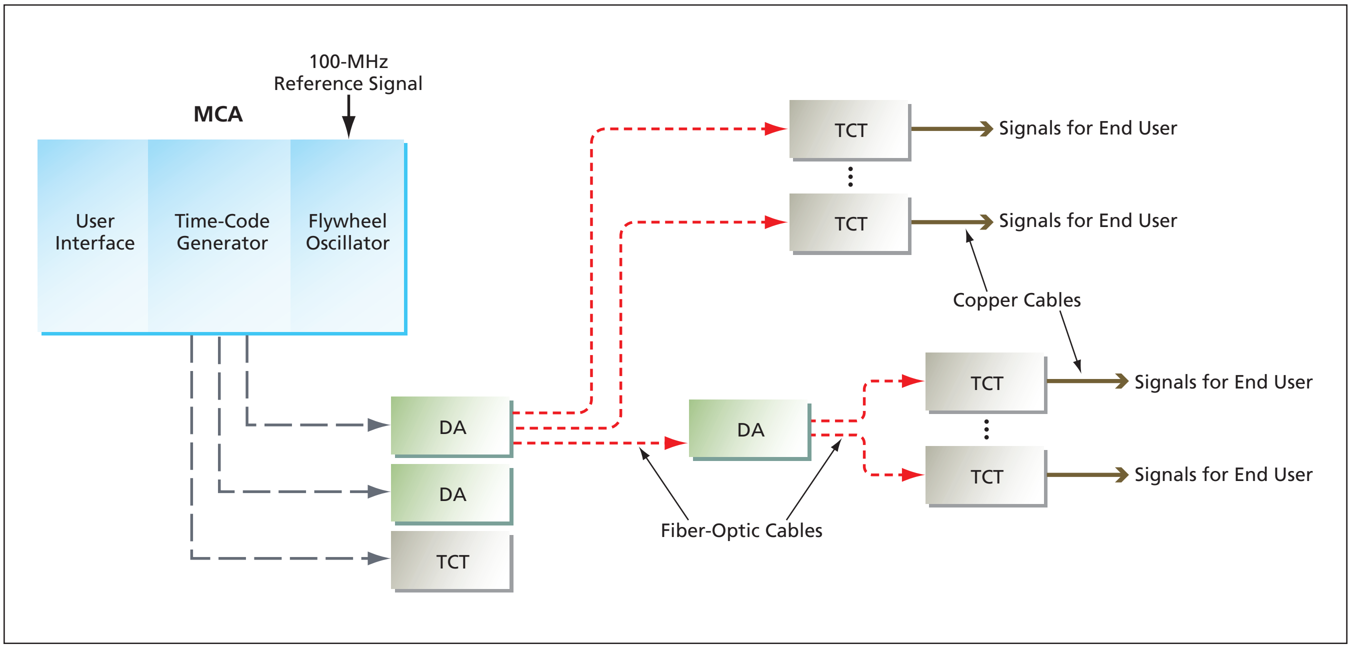


The **Timing System** consists of hardware modules interconnected by fiber-optic cables. This block diagram is a highly simplified representation: The real system has a more complex fan-out, with more modules, cables, and end users.

blanked pulse by turning on an LED in the DM. Each DA chassis contains one alarm representing the summed alarms of all 10 of its DMs. This alarm is passed further back up the hierarchy or collected by a status summary monitor computer visible to operators. With modularity and simple "go/no-go" monitoring and alarm information, operators can maintain operations with little understanding of the nuances of the precise timing system.

This work was done by Robert Tjoelker, Malcolm Calhoun, Paul Kuhnle, Richard Sydnor, and John Lauf of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-40851

Synchronous Phase-Resolving Flash Range Imaging

Complete range images are generated, without scanning, at a video frame rate.

NASA's Jet Propulsion Laboratory, Pasadena, California

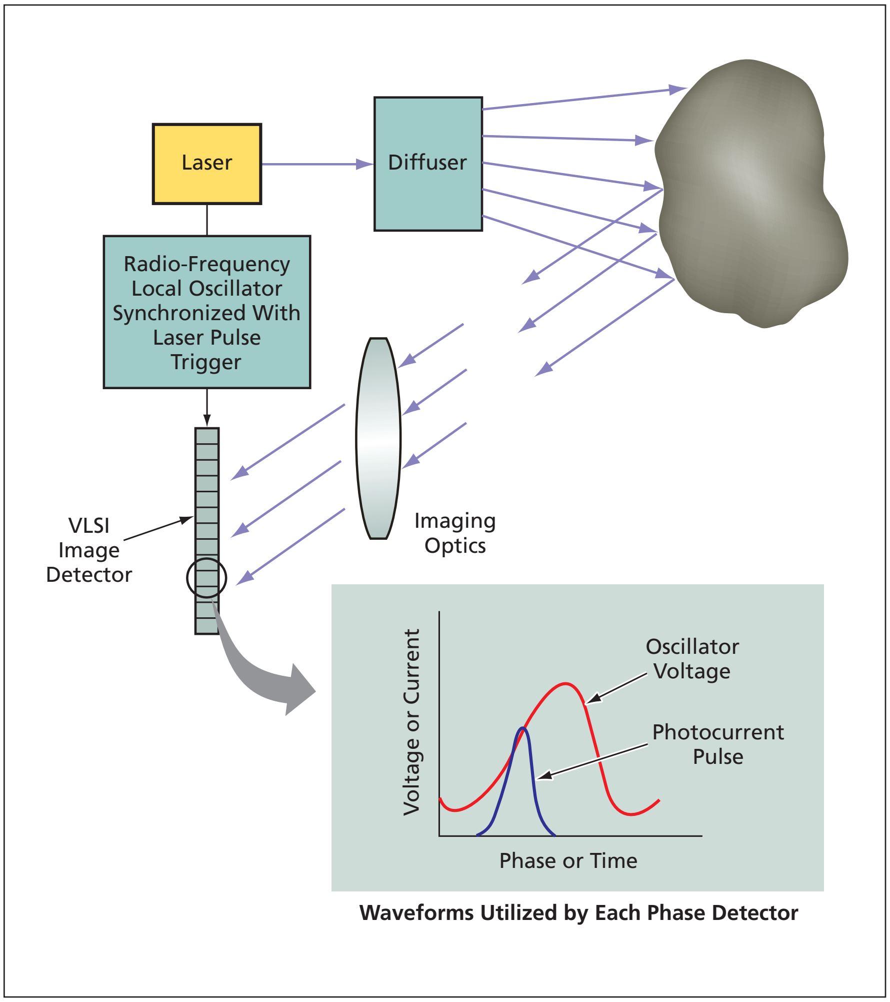
The figure is a simplified diagram of an apparatus, now undergoing development, for range imaging based on measurement of the round-trip phase delay of a pulsed laser beam. Variants of this apparatus could be used to provide range information needed for navigation of autonomous robotic ground vehicles and robotic aircraft, and for navigation and aiming in numerous military applications.

The apparatus would operate in a staring mode. A pulsed laser would illuminate a target. Laser light reflected from the target would be imaged on a very-large-scale integrated (VLSI)-circuit image detector, each pixel of which would contain a photodetector and a phase-measuring circuit. The round-trip travel time for the reflected laser light incident on each pixel, and thus the distance to the portion of the target imaged in that pixel, would be measured in terms of the phase difference between (1) the photodetector output pulse and (2) a local-oscillator signal that would have a frequency between 10 and 20 MHz and that would be synchronized with the laser-pulse-triggering signal.

This apparatus offers several advantages over prior laser range imagers (essentially, scanning lidar systems based on explicit measurement of round-trip pulse travel times). A typical scanning lidar system consumes tens of watts of power, must be large because of the need for complex optics and mechanical scanning, and must include a clock running at a frequency of the order of a gigahertz. Moreover, because of the need for mechanical scanning to build up a range image, it is not possible to achieve an update rate (frame rate) sufficient for most applications.

In contrast, because of its staring mode of operation, the developmental apparatus could utilize simpler optics and would contain no moving parts. Because of the elimination of mechanical scanning and the use of VLSI circuitry, the power demand of this apparatus would be only about 100 mW. Moreover, because a complete range image could be constructed for each successive laser pulse, it would be possible to achieve an update rate, greater than the standard video frame rate of 30 Hz, that would be sufficient for most robotic applications. It has been estimated that the apparatus could provide a range resolution of 1 cm. The maximum range of the apparatus would depend on the details of the design and the specific application: for example, on the basis of the minimum detectable photocurrent density, the maximum range would be about 1 km for a 15°-wide field of view or about 100 m for a 60°-wide field of view.

A prototype of the phase-measuring VLSI image detector has been demonstrated. In each pixel, the output of the photodiode and the local-oscillator sig-



In this **Lidar Range-Imaging System** voltage-to-phase converter circuits in each pixel that would be used to measure the phase of the lidar return pulse relative to the phase of a local-oscillator signal synchronized with the laser pulse.

nal are fed as inputs to a current-mirror circuit to obtain output currents proportional to the value of the local-oscillator sinusoid at the time of return of the laser pulse. In each of several phase-detector circuits, one of the current-mirror output currents is integrated in a capacitor to obtain a low-noise voltage indicative of the phase difference. This design enables accurate measurement of the phase difference because it is possible to measure voltage very accurately (to within microvolts) in VLSI circuits. The use of several phase detectors, each excited with a differently delayed replica of the local oscillator signal, makes it possible to measure the target distance accurately in the presence of unknown background illumination, unknown target albedo, and full-cycle phase ambiguities.

This work was done by Bedabrata Pain and Bruce Hancock of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Integrated Radial Probe Transition From MMIC to Waveguide

Packaging based on wire bonding would be supplanted by monolithic integration.

NASA's Jet Propulsion Laboratory, Pasadena, California

A radial probe transition between a monolithic microwave integrated circuit (MMIC) and a waveguide has been designed for operation at frequency of 340 GHz and to be fabricated as part of a monolithic unit that includes the MMIC. Integrated radial probe transitions like this one are expected to be essential components of future MMIC amplifiers operating at frequencies above 200 GHz. While MMIC amplifiers for this frequency range have not yet been widely used because they have only recently been developed, there are numerous potential applications for them — especially in scientific instruments, test equipment, radar, and millimeter-wave imaging systems for detecting hidden weapons.

One difficult problem in designing and fabricating MMIC amplifiers for frequencies greater than 200 GHz is that of packaging the MMICs for use as parts of instruments or for connection with test equipment. To package an MMIC for use or testing, it is necessary to mount the MMIC in a waveguide package, wherein the cross-sectional waveguide dimensions are typically of the order of a few hundred microns. Typically, in an MMIC/waveguide module for a microwave frequency well below 200 GHz, electromagnetic coupling between the MMIC and the waveguides is effected by use of a microstrip-to-waveguide transition that is (1) fabricated on a dielectric [alumina or poly(tetrafluoroethylene)] substrate separate from the MMIC and (2) wire-bonded to the MMIC chip. In the frequency range above 200 GHz, wire bonding becomes lossy and problematic, because the dimensions of the wire bonds are large fractions of a wavelength. In addition, fabrication of the transition is difficult at the small required thickness [typically of the order of 1 mil (25.4 μm)] of the dielectric substrate. The present design promises to overcome the disadvantages of the separate substrate/wire-bonding approach.